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ON THE GNEISSES FROM A PART OF THE NORTH-WESTERN GNEISS AREA OF SOUTHERN NORWAY

BY

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Contents.

Abstract. The north-western part of Southern Norway is an area mainly of gneisses, formerly regarded as entirely of Archean age. In later years a number of writers have maintained that parts of the gneisses are Caledonian migmatites and that the parts of the gneisses of Archean origin have been influenced by tectonical movements and by migmatisation during the Caledonian orogeny.

The scope of the present paper is to describe the gneisses occurring in the regions of Lesja — Romsdalen and Otta valley — Grotli (sketch map Fig. 1).

The rocks are quartzdioritic gneisses very poor in potash feldspar, with subordinate bands of amphibolite. Schistose anorthosites occur at two localities. Closely associated with the plagioclase gneisses are gneisses with considerable amounts of potash feldspar. Microscopical study of these rocks gives strong indications of the secondary introduction of the potash feldspar by corrosive replacement processes. During these processes potash feldspar is added to the rock, to a great extent at the expense of the original plagioclase. There is also an increase in the amount of quartz and a strong decrease in the amount of ferro-magnesian minerals.

The plagioclase gneisses, thus the motler rocks of the granodioritic gneisses, are regarded for a great part as of Archean age, while the granitisation process, by which great amounts of potash feldspar was introduced, is indicated as being of Caledonian age.

Introduction.

An area consisting mainly of gneisses extends along the west and north-west coast of Southern Norway from south of the Sognefjord at about 60 1/2° lat. N to the boundary to Northern Norway at about 65° lat. N. This area is bounded to the southeast by the Eo-Cambrian and Cambro-Silurian sediments in the fosse of folding (Faltungsgraben of V. M. Goldschmidt (1912)) and in the great synclinorium of the Trondheim Region further north. Also within this gneiss area there are synclinal tracts of metamorphosed Cambro-Silurian sediments and post-orogenic deposits of Downtonian and Devonian age.

This area has been called the North-Western Archean Area of Southern Norway, but today the North-Western Gneiss Area would be a better and more non-committal term. For the sake of brevity it will be referred to in this paper as the *gneiss area.*

The gneisses (and granites) of this area are marked as Archean on the geological map of Southern Norway in scale 1: 1 000 000 published in 1915. That this was not, however, unanimously accepted is apparent from the literature published at that date. Thus Th. Kjerulf (1871) assented a Caledonian age for some granites in the "Vestrand", the coastal region between Kristiansund and Namsos (between 63° and 65° N). J. Schetelig (1913) considered the granites in the same area to be extensions of the large granitic massifs of Caledonian age in Northern Norway.

In a number of papers published in later years O. Holtedahl (1936, 1938 b, 1944) has refuted the conception of the gneisses being simply Archean. In the text to a geological map accompanying his treatise of 1944, the gneiss area is designated as "Basal crystalline complex of relatively central orogenic districts .... Rocks believed to have been mainly formed by high-grade metamorphism, migmatization and granitization of pre-existing rocks (Archean, Eo-Cambrian, Cambro-Silurian)."

In the Opdal district, at the western side of the Trondheim Region, about 62° 35′ N, a granodioritic gneiss (basal gneiss of Holtedahl) lies conformably below Sparagmitian rocks. Holtedahl (1938 a) and Barth (1938) were inclined to regard this rock as a wholly Caledonian migmatite. Later Rosenqvist (1941) detected a conglomerate between the basal gneiss and the base of the Sparagmitian flagstones. The basal gneiss thus seems to be of Archean origin, whatever may have been its transformation in Caledonian times.

C. F. and N. H. Kolderup (1940) describe the rocks of the Bergen Arcs, which are partly Cambro-Silurian sediments with their intrusives, partly rocks of the Anorthositic (or Bergen—Jotun) kindred. The gneisses forming the frame of these rocks are considered as migmatites of Caledonian age and, to some extent at least, derived from Cambro-Silurian sediments.

In the Bergsdalen area east of Bergen Kvale (1946) describes gneisses of the same group as Caledonian migmatites. The rocks in question are granodioritic gneisses with thousands of dykes and veins of granite, with or without a sharp boundary to the wall rock.

A paper by M. Richter (1943) contains some interesting observations on the granitisation of sediments, which he regarded as of Ordovician age, in the peninsula of Ørlandet on the north side of the mounth of the Trondheimsfjord. But when this author in the same paper concludes on the absence of any Pre-Cambrian material within the whole gneiss area, it is a generalisation quite unwarranted by his observations within a limited area.

H. Ramberg (1944) gives a thorough petrographical description of rocks in areas around the mouth of the Trondheimsfjord (a part of the "Vestrand"). Parts of the geisses in this area are regarded as being of metasomatic origin and with a derivation from sediments of the Caledonian cycle.

T. Gjelsvik (1947) gives a very short note, the only thing yet published, on the investigations within the gneiss area in Sunnmøre, south of the Romsdalsfjord, carried out in later years by himself and associates. His general view on the geology of the region tallies with that of Holtedahl.

In the coastal regions in the northern parts of the gneiss area there are bands of crystalline limestone embedded in the gneisses, as described by C. Bugge (1906) and by H. Ramberg (1944). During his limestone studies Dr. Carl Bugge observed micaschists in grey gneisses not far from some of the limestone deposits in the parish of Bud north of Molde. Dr. Bugge suggested that the writer should visit the locality, which is at the rectory of Bud, and thus the writer was able to observe somewhat feldspatized rocks, clearly recognizable as wrinkled micaschists at that locality. The micaschists pass into the gneisses, and the same wrinkling and other folding patterns may also be observed in the gneisses. No doubt the grey gneisses — with amphibolite bands — which enclose the limestones, are granitisation products of pelitic rocks.

In the Surnadal syncline, striking to the south-west from the Trondheim Region proper, the lower parts of the Cambro-Silurian sedimentary sequence are transformed into gneisses. Below the gneisses are rocks recognizable as sparagmites.

The Surnadal area shows sediments, undoubtedly of Cambro-Silurian age to pass over into migmatite gneisses of the same type as are generally met with within the Archean. Now in many localities within the gneiss area we find similar migmatites with remants of micaschists, thus evidently derived from sediments by metasomatic processes. There are strong reasons to suspect a Cambro-Silurian age of these sediments and a Caledonian age of the migmatites derived from them.

These migmatite gneisses contrast with a group of much more homogeneous gneisses found in regions of the Sundalsfjord, Ålvundfjord and Todalsfjord. At the tourist station Kårvatn in the Todalen valley these rather massive and homogeneous gneisses are overlain towards the east by a thick series of micaceous quartzites, certainly Sparagmitan rocks. At the road 2 km west of the ferry of Kvande on the Todalsfjord the same gneisses are overlain, with a sharp boundary, by a thin zone of quartzite, above the quartzite follow Caledonian grey gneisses of the Surnadal syncline. The homogeneous gneisses are thus indicated as belonging to the Pre-Cambrian basement underlying the Caledonian rocks.

The titaniferous iron ore deposits of Raudsand and Meisingset, deposits of the Raudsand type (Carstens 1939) are situated within the areas of homogeneous gneisses referred to above (cf. Foslie 1925, p. 22). The irion ore deposits of this type must accordingly be of a Pre-Cambrian age and can serve as indicators of a Pre-Cambrian origin of the parts of the gneiss area in which they occur.

Future research within the gneiss area will have to aim at a distinction between Caledonian migmatites and Pre-Cambrian massifs. For the latter one must also try to find out to which degree they were influenced during the Caledonian orogeny as to tectonics and metamorphism and metasomatism.

A point of departure for the present studies were the gneisses at the boundary to the Caledonian sediments in the Otta valley

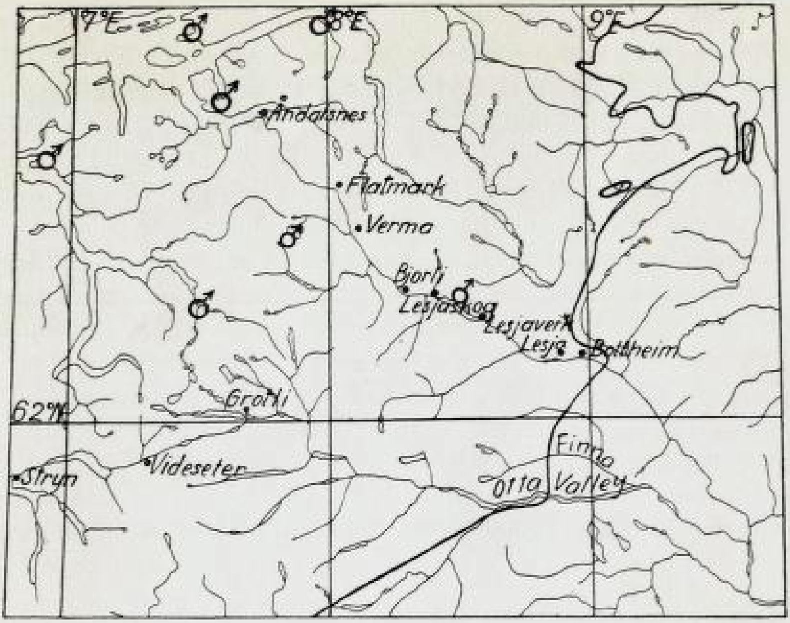

Fig. 1. Map to show the localities of the rocks described in the present paper. The line marks the boundary between the Caledonian sediments to the east and south-east and the gneisses to the west and north-west. Deposits of titaniferous iron ores are marked according to Foslie (1925).

and the regions to the north of this valley, in the Vågå area mapped by the writer. From here excursions were made to the regions to the west, to Lom, Grotli and Stryn. A rather rapid reconnaissance survey was also made along the line of the road and railway from the eastern boundary of the gneiss in Lesja in Gudbrandsdal to Åndalsnes on the Romsdalsfjord.

Perhaps an apology may seem called for, for publishing anything on the geology of such an extensive area with so little of material or observations. The reasons for doing so are, firstly, that the published information on these areas contains little more in the way of facts than that the rocks are gneisses (exception must be made for the description of rocks and iron ores of Lesja by Carstens (1928) and of a hornblende-gabbroeclogite from the foot of Romsdalshorn by Eskola (1921)), and secondly, that the rocks seem to be of very uniform types throughout the area.

The gneisses which are to be described in the sequel are for one part of a quartzdioritic composition with plagioclase as the only feldspar, apart from small amounts of potash feldspar occuring as antiperthitic inclusions within the plagioclase grains. For another part they are of a granodioritic to granitic composition with potash feldspar as an essential constituent. Both from field and microscopic studies there are indications pointing to a secondary introduction of most if not all of the potash feldspar by metasomatic processes to be classed under the general head of granitisation. Thus during one part of its history the whole complex of gneisses here described may have consisted of plagioclase gneisses. For this reason the plagioclase gneisses and their supposed derivates, more or less rich in potash feldspar, will be described separately.

Besides his own material, in the collection of the Geological Survey of Norway, the writer has been allowed to utilize rock specimens and thin-sections from the same regions in the Mineralogisk-Geologisk Museum of the University of Oslo, thanks to Prof. Ivar Oftedal.

Field description of the rocks.

The plagioclase gneisses.

The rocks in this group are on the whole very uniform, the dominating rocks being grey gneisses, the colour of which is caused by the light plagioclase and quartz and the dark biotite. Much more seldom are darker gneisses tending towards amphibolites with amphibole as an essential constituent. Variation in the aspect of the rocks is caused partly by a varying content of biotite, but perhaps more by the variation in grain size. Fine-grained rocks show a uniform grey, while in the coarse-grained ones the white of the quartz and plagioclase and the black of the biotite may give a speckled appearance.

Most of the rocks have a distinct plane schistosity, and in most cases a linear structure can also be observed and measured. Generally the gneisses have a parting into benches with a thickness measurable in decimetres. More exceptionally the gneisses

Fig. 2. Banded gneiss at the railway station of Verma in Romsdal. In the grey gneiss there are dark bands rich in biotite and light streaks of quartz and feldspar.

are without any plane schistosity and have a very massive appearance in outcrops. Gneisses of this type have been observed on the north side of the Finna valley.

Banding is a most characteristic feature of the gneisses. This does not imply the occurrence of a pronounced banding in any one outcrop, the majority of the rocks are uniform grey gneisses, perhaps with some light streaks only, but a good example of a banded rock can be found in any part of the area. The banding is produced by a varying biotite content, and thus stripes and bands of light grey to almost black rocks alternate. The photograps (Fig. 2, 3) will give a better impression of the banding than long descriptions, but one feature may be stressed: the bands are not very sharply deliminated, but has a general resemblance to alternating layers of sedimentary rocks.

Black bands of amphibolite are sharply delimited and make a striking addition to the band architecture.

Fig. 3. Banded gneiss. Road section west of Veblungsnes, about 2 km south-west of Åndalsnes, horizontal surface. A match (5 cm) to serve as a scale.

A remarkable member of the gneiss complex is anorthositic schist, observed by the writer at two localities. One occurrence is to the north-east of the Grotli hotel, 1050 to 1100 m above sea level on the north-east side of a brook valley. The anorthositic schist here has a thickness of about 50 m and contains bands and lenses of dark amphibolite, to the north-east of it a grey gneiss follows, which contains a band of anorthosite only 2 dm thick. A second, and larger, band of almost massive anorthositic rock then follows to the north-east.... The other occurrence observed by the writer is on the south side of the river Rauma just west of the railway station of Lesjaskog. Here an anorthositic rock is exposed for a distance of about 100 m in north—south direction across the strike of the vertical schistosity, which is distinctly marked in the rock. Here too the anorthosite contains narrow bands of amphibolite. No boundary to side-rocks is exposed; proceeding south one meets with grey gneisses with narrow bands of amphibolites and of highly schistose anorthositic rocks. To the east of the anorthositic rock, about in the direction of the strike, exposures of massive amphibolitic rocks were observed. The same association of anorthositic, gabbroid and quartzdioritic rocks, here with titaniferous iron ores, were described by Carstens (1928, p. 75) from the old iron mines of Lesja, situated about 5 km to the east, as the crow flies, and thus probably in the continuation of the strike from the locality described above.

In one limited area sediments have been observed as an integral part of the gneiss complex. In the region of Grotli there are light to reddish quartzites with muscovite and microcline, similar to the light sparagmites. Rather large outcrops of these rocks occur east of Grotli, at the road north of Lake Heimdalsvatn. Cross-bedding has been observed in the quartzites and also a thin band of a rock resembling quartz conglomerate. The section in Fig. 4 is from an easily accessible locality near Grotli hotet. In many parts of the section wholly concordant boundaries between quartzite and gneiss can be observed, which do not favour an interpretation of the gneiss as an igneous rock intrusive into the quartzite. A narrow band of quartzite,

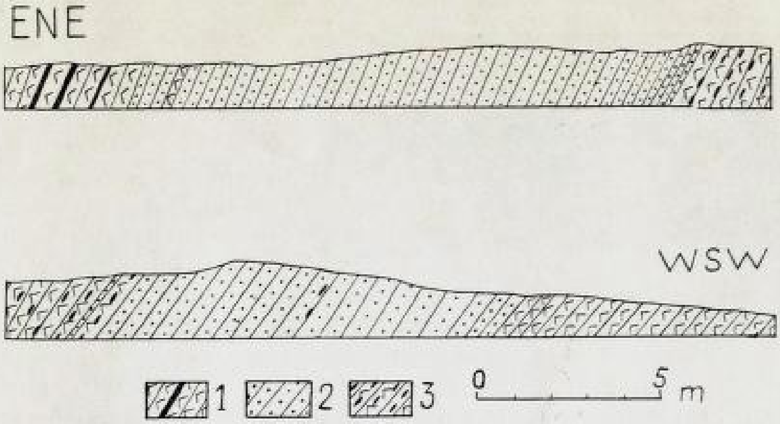

Fig. 4. Section about 1 km south of the Grotli hotel, along the river from Lake Breiddalsvann, east of the road leading to Stryn. 1. Grey plagioclase gneiss with bands of amphibiolite. 2. Quartzite. 3. Green scapolite — amphibole rock, spots of the same green colour has also been observed in the quartzite.

2 dm thick, embedded in a green scapolite-bearing gneiss to be described later, is especially convincing in this respect.

In most outcrops the gneiss benches have a uniform strike and dip, but outcrops showing folding are not so very rare. The folds may be low, broad arches, but they may also be of an irregular and unsymmetrical type, indicating a plastic state of the material during folding.

The granodioritic and granitic rocks.

The Lesja—Romsdal area.

Wegmann (1935, p. 337) has announced the occurrence of a migmatite front at the boundary between the gneisses and the Caledonian sediments in the eastern part of Lesja. In the northern slope of the valley, in the region of the railway station of Lesja (which is marked down as an area of granite on the map of K. O. Bjørlykke (1905, p. 356)) a homogenous, reddish, granitic rock is exposed. The granitic gneiss has a distinct lineation, but no marked foliation, and appears massive in sections normal to the lineation. The rock has close-lying

Fig. 5. Folds in the gneiss at the railway station of Verma in Romsdal. The axes of folding pitch faintly to the east, in direction away from the camera, south is to the right.

porphyroblasts of reddish potash feldspar of centimetre size and at some places has the character of an augen-gneiss. A closer inspection of the outcrops often reveals patches of a dark, fine-grained rock matrix in the gneiss, which suggests the origin of the coarse gneiss to be by feltspatisation of a fine-grained gneiss. Indications as to the correctness of such a supposition is given by a loose block found on the mountain plateau above the valley slope. This rock consists in parts of a granitic gneiss with feldspar augen of centimetre size, in other parts of a light, grey, fine-grained rock (Nos. 16—17).[1] The irregular and diffuse boundary between the rocks excludes the possibility of either of them being intrusive into the other.

Farther east, between the railway stations of Lesja and Bottheim, an automobile road ascends the north slope of the valley in an easterly direction. The lowermost exposures at the road are of a homogenous, reddish, granitic gneiss, Patterns of intricate folding were observed in a gneiss with bands of biotite-epidote rock, probably an original amphibolite. At about 850 m a. s. l. the homogenous rock passes into an augen-gneis with a dark matrix (No. 22), then at 900 m a. s. l., at the margin of the plateau above the valley, a dark grey gneiss follows. — — In railway and road sections near the railway station of Bottheim there are banded plagioclase gneisses (No. 4), and also gneisses with large augen of reddish potash feldspar, which are marked on a section by K. O. Bjørlykke (1905, p. 357). As in general

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[1] See the table on p. 41.

in the gneisses in these areas, the augen are clusters of feldspar grains and not single crystals or twins.

In Lesja we thus meet with a migmatite front marked by a zone of augen-gneisses, Above the front there are grey plagioclase gneisses, below the front these have evidently been transformed into homogenous granodioritic or granitic gneisses. The occurrence of larger masses of homogenous granitic rocks is particular to the area here described.

In the northern slope of the valley just west of the railway station of Lora, 8 km west of the Lesja station, light granitic gneisses, very poor in dark minerals, were found intercalated with amphibolites in almost horizontal position. Farther west, near the railway station of Lesjaverk, there are a few exposures of a light, coarse-grained gneiss with diffusely delimited schlieren of pegmatite.

In the region of Lesjaskog, the rocks on the southern side of the valley near the locality of the anorthosite described above, contain little of potash feldspar, to judge from field observations. On the northern side of the valley it is mainly granitic gneisses which are exposed along the River Mølmå.

In road sections from Lesjaskog towards Verma, in Romsdal, the plagioclase gneisses are coarse-grained rocks and generally alternating with bands of reddish granitic rocks poor in dark minerals. Nos. 18—19 are examples of such rocks from adjacent bands. Pegmatite veins and schlieren are of general occurrence, and are mostly parallel to the foliation of the rocks, though they do sometimes cut the foliation.

Along the Romsdal valley, from between Verma and Flatmark to Åndalsnes, the rocks are for the most part massive veined gneisses, though in these regions too it is easy enough to procure hand specimens of plagioclase gneisses containing very little potash feldspar. The veins rich in potash feldspar and quartz are generally about one centimetre wide (figs. 6—7). Pegmatite veins and schlieren are common, and large vertical veins, with an estimated width of one metre, were also seen in the inaccessible steep walls at the sides of the valley. The rocks are of a very massive appearance and display joints in a horizontal position (or at least with horizontal traces in the

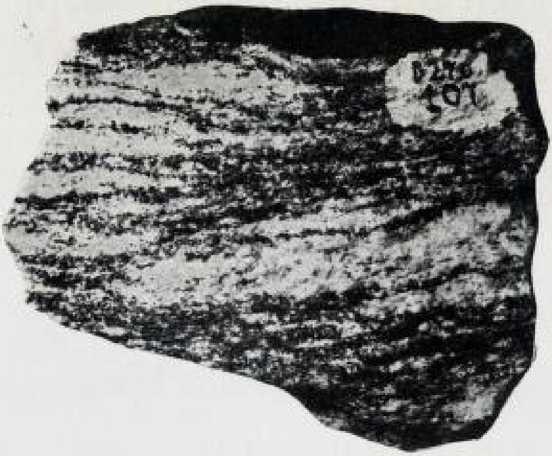


Fig. 6. Hand specimen of veined gneiss, road section at the foot of Romsdalshorn, between Flatmark and Åndalsnes. Faintly reddish veins very rich in potash feldspar in a matrix of plagioclase gneiss. × 2/3.

steep walls). At the foot of the Romsdalshorn mountain coarse augen-gneisses are exposed just above the road, the augen consisting of cigar-shaped clusters of feldspar elongated in the lineation of the rock. These exposures are only about 20 m above sea level; augen-gneisses and veined gneisses of the same types occur at the summits of the Romsdal mountains, 1500 to 1600 m above sea level, as can be seen from rock specimens in the Geologisk Museum in Oslo, collected by the Danish alpinist, Mr. Carl Hall. At the road west of Veblungsnes

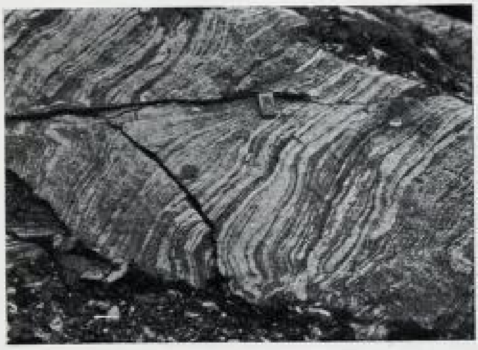


Fig. 7. Veined gneiss. Road section at Innholmen, 6 km west-south-west of Åndalsnes. A match-box (5 cm) to serve as a scale.

Fig. 8. Hand specimen of dark dioritic gneiss with light granitic veins, Videseter hotel, Stryn.

the banded plagioclase gneiss (fig. 3, No. 9) is distinctly seen to be an enclave which has been spared of the granitisation and is surrounded by rock full of pegmatites and other feldspar veins.

The region of the Otta valley, Grotli and Stryn.

Near the boundary between the gneiss and the Caledonian sediments at Lake Vågåvatn there are smaller parts of granitic rocks, often augen-gneisses, and also pegmatites alternating with the plagioclase gneisses. Augen-gneisses seem to be rather common in these tracts. In the region south of the mountain Snauskallen, in Lom, there are fine exposures of banded rocks, among which the reddish granitic bands are also conspicuous.

Further west, in the Grotli region, there seem to be great masses of plagioclase gneisses with little introduced potash feldspar. East of the anorthositic bands described on p. 12 there is a banded rock. In hand specimen and in microscopical section this rock displays an alternation of reddish stripes with much potash feldspar and few dark minerals and grey or dark stripes of more or less unchanged plagioclase gneiss.

The specimen in fig. 8 was taken from a road section near Videseter hotel in Stryn. This is an example of granitisation which might at first sight seem to have occurred through an injection of granitic material into fissures opening in the rock. The photograph, however, shows streaks of biotite extending from the dark host rock through the light granitisation veins, which testify against the existence of open fissures in the rock. The dark rock is an amphibole-bearing gneiss; the light veins contain microcline, in small grains, as well as in porphyroblasts of up to centimetre size, much quartz and very little of dark minerals (Nos. 20—21).

Petrographical description of the rocks.

The plagioclase gneisses.

The plagioclase gneisses contain the following minerals:

Quartz occurs in some cases in grains of about the same size and shape as the plagioclase grains. It may also occur as small drops or blebs within plagioclase grains. More commonly it occurs in veins, generally one to two millimetres thick, which penetrate the structures formed by the other minerals of the rock. Grains of the other minerals of the rock are often found included in the quartz veins with an appearance of detached fragments. Generally the quartz in the veins has a more or less strongly undulating extinction and highly irregular and sutured outlines of the individual grains.

Plagioclase is in most cases an oligoclase or a sodic andesine, but in some few rocks it is albite.

When albite occurs it is mostly of a type resembling chess-board albite in that it has twin lamellae with a truncate termination within the grain, but as the twin lamellae thus truncate are very narrow, a regular chess-board pattern is not produced. — The common calcic plagioclase is usually twinned on (010), somewhat less commonly on (001). A distinctive character of the plagioclase is inverse zoning of the grains, with a less calcic core and more calcic rim, a feature shown by some grains at least in every slide of the gneisses. The difference in composition

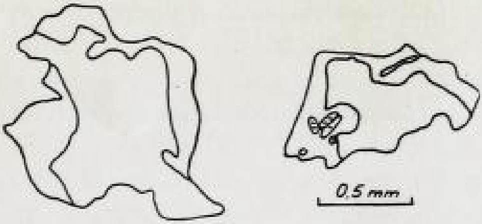


Fig. 9. Inversely zoned plagioclase grains from the schistose anorthosites of Grotli (D28v 101 & 102). The boundary between the irregularly outlined core and rim is sharp and can be observed in parallel light by means of the Becke line. In the grain to the right inclusions of epidote and biotite in the rim part.

between core and rim may amount to as much as 10 per cent of anorthite. The borders between core and rim have no relation to the outline of the grain. The core may be situated almost at the margin of the grain and there may also be more than one core, a mottled appearance thus being given in polarized light. Commonly there is a gradual transition between the zones, but there may also be more sharp contrasts, so that the boundary between core and rim part of a grain may be observed in parallel light by means of the Becke line. In some cases the outline of the less calcic core part of the grain may be quite irregular, as in the grains figured in fig. 9. In such cases a resorption of an earlier less calcic plagioclase is indicated as antedating the formation of the more calcic rim part of the grain. In some rocks there are also inclusions of plagioclase in plagioclase, which may be interpreted in the same way. Mention may also be made in this connection of the very irregular sutured margins of the plagioclase grains of some rocks.

Potash feldspar as an original constituent of the rocks occurs in small amounts only, and then as antiperthitic inclusions within plagioclase grains. The bulk of the potash feldspar found within the complex is regarded as of replacement origin and will be treated in a later chapter. The antiperthitic inclusions are as a rule rectangular in shape with the sides parallel to (010) and (001) of the host plagioclase. Antiperthites of this type are best interpreted as being formed by simultaneous crystallisation of the two feldspars. In rocks where the replacement formation of potash feldspar is evident, the antiperthitic inclusions become large and irregular. In such cases the original antiperthite has probaby developed into one of replacement type.

Epidote is an essential constituent in some rocks of lower minerel facies, in which the plagioclase can contain only a limited amount of anorthite in solid solution. In other rocks it occurs in small amounts, generally in association with biotite, in some cases as scattered porphyroblasts, formed secondarily at the expense of plagioclase. Often the grains have a core of a yellowish orthite-epidote. Larger grains are often zoned with a less iron-rich core, sometimes even of clinozoisite. In rare cases only a clinozoisite or a zoisite poor in iron is found.

Biotite is a typical constituent of the grey gneisses. There seems from the colour to be two main types of biotite, one of a dirty greenish-brown and the other of a pure light or dark greyish-brown.

Green amphibole of a common type is a main constituent of the amphibolites and is also found in some gneisses tending towards amphibolites. Amphiboles, partly of another type, possibly of replacement origin, will be dealt with in a later chapter.

Garnet is found in some rocks, but the mineral is in small amounts only and is not of wide distribution.

Muscovite may occur in some rocks in small amounts and in small irregular grains, probably as an alteration product of plagioclase. In some rocks the mineral occurs in large porphyroblasts.

Sphene, *iron ore* and *apatite* are common accessories, and *zircone* has also been observed.

In the table on p. 41 Nos. 1—14, 16, 18, 20 give data of the mineral composition in per cent of volume according to measurements by the Rosiwal method of plagioclase gneisses and associated rocks (Nos. 11 and 12 are anorthosites). Short descriptions of the rocks are given in the text accompanying the table. Also some rocks with small amounts of potash feldspar, apart from antiperthitic inclusions, are included in this assemblage. Also in these cases the potash feldspar is regarded as introduced in the rock, but the process of introduction is in an incipient stage only.

Rocks believed to have been formed by metasomatic alterations of the plagioclase gneisses.

This group comprises the granitic and granodioritic gneisses already referred to, which are indicated as having been formed from plagioclase gneisses essentially by a potash metasomatism. It also comprises some rocks which seem to be more or less influenced by a lime metasomatism: the scapolite-bearing gneisses of Grotli and some gneisses with large, scattered porphyroblasts of amphibole, which are indicated to have grown at the expense of biotite.

These rocks contain for a great amount minerals also present in the plagioclase gneisses: plagioclase, epidote, quartz, biotite and accessories. The below list comprises the minerals believed to have been formed during the metasomatic processes.

Quartz. In most instances the granitisation is accompanied by an increase of the amount of quartz. The quartz thus formed is often a vein quartz with the same structure as has already been described in connection with the plagioclase gneisses.

Potash feldspar. Small grains of potash feldspar show no twinning, and the absence of cleavage cracks prevents an identification either as orthoclase or microcline. Larger grains show the microcline twinning, which is characterized by hazy outlines of the twin lamellae; in some grains there is a shadowy extinction wandering through the grain during a rotation of the stage. The larger porphyroblasts of microcline may be perthitic with spindles of albite; these are comparatively broad and few in number, and sometimes they anastomose. — The structures of the potash feldspar, which provide convincing evidence of the secondary introduction of the mineral, are to be described later on.

Myrmekite constantly occurs in association with potash feldspar. It may sometimes be found as wart-like protrusions at the margin of larger porphyroblasts of microcline and often as inclusions in such. In other cases there are only small grains of potash feldspar associated with the myrmekite. The form of the myrmekite grains is variable and the outline may be quite irregular. In some rare caces myrmekite occurs as a

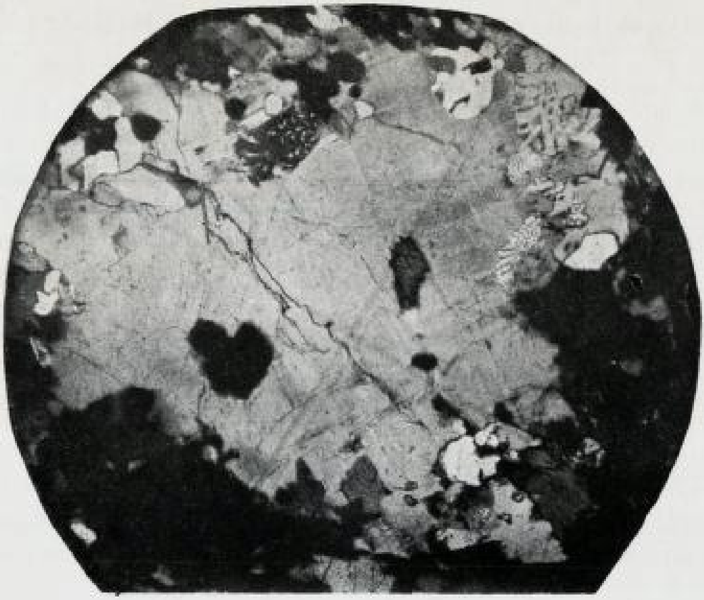
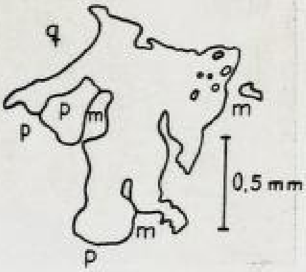


Fig. 10. Numerous inclusions of myrmekite in a porphyroblast of microcline-Granodioritic gneiss E29ø 46. Nic. +, × 30.

part of larger plagioclase grains, in most cases the whole grain is myrmekite with inclusions of quartz. The size of the grains is usually about 0,5 mm. In the rocks studied here the plagioclase of the myrmekite has the same composition as other plagioclase of the rock, or, as far as can be determined, is within the same range of variation. The myrmekite is of the usual, characteristic type, and a separate description here is thought to be superfluous.

According to Becke's well known theory myrmekite is formed by replacement processes at the expense of potash feldspar. Now, in the rocks here described the potash feldspar seems to have been formed by metasomatic processes, for a great part, at least, at the expense of plagioclase. Departing from the Becke theory, one might assume the formation of myrmekite to belong to a later phase in the history of the rocks, when the conditions were reversed, so as to favour the formation of plagioclase at the expense of potash feldspar.

Fig. 11. A plagioclase grain in granodioritic gneiss E28ø 103 (No. 17). The adjacent minerals are plagioclase (p) and quartz (q) on the left and microcline (m) on the right. The very irregular outline towards the microcline and a detached fragment enclosed in the same mineral indicate resorption of the plagioclase. In the upper right part of the plagioclase grain there are myrmekite inclusions of quartz.



Sederholm in his treatise on myrmekite (1916) adopted Becke's theory, but he also gave evidence of some cases in which the theory must fail, as myrmekite is found in rocks in which there is no potash feldspar (l. c., p. 77 (citation from Osann), p. 120). Here the formation of myrmekite is ascribed to the corrosive effect of silica upon the plagioclase. The present writer has observed myrmekite of rare occurrence in some Caledonian gneisses, in which albite is the only feldspar.

In the rocks here described there are indications that the myrmekite originated from the plagioclase already present in the rock. It is impossible to distinguish between the plagioclase of the myrmekite and other plagioclase of the rock, both seem to have the same composition and both are saussuritized to the same degree. As already mentioned, myrmekite can also form part of larger plagioclase grains, even if these are to all appearances in a state of resorption (fig. 11). In one case an assemblage of myrmekite "quartz-worms" have been found enclosed in microcline. In other cases quartz inclusions have been found in potash feldspar, these quartz inclusions being in the same optical orientation as in the neighbouring myrmekite. These observations must indicate a resorption of the myrmekite plagioclase.

Thus Becke's theory on the formation of myrmekite seems to fail in the present case. It must fail for the rocks here in question, if the writer's interpretation of their history should be correct.

Amphibole, possibly of replacement origin, is found in a number of rocks to be described in the sequel. In many cases

Fig. 12. Granodioritic gneiss, E29ø 47 (No. 15) Parallel light, focus a little below the plane of the section, to let the light Becke line pass into the grains of potash feldspar, to show the irregular pattern of the outline of this mineral to adjacent pladioclase x 40.

the amphibole of this mode of formation has strong absorption colours and a rather small axial angle with a strong dispersion, indicating a high tenor of iron. The absorption scheme of the various amphiboles is γ blueish-green, β olive green, α yellowish.

Pyroxene is found in one case together with amphibole. It is a clionopyroxene of common type, $+2V\,60^\circ$ app., $c \wedge \gamma$ 40° app., dispersion $r > v$.

Scapolite has been found in a few rocks described in the sequel. Diagnostically it shows uniaxial negative character and tetragonal prismatic cleavages. In the Grotli scapolite the birefringence is 0.020—25, indicating a composition about Ma55Me45.

Epidote and *clinozoisite*, evidently of replacement origin, are found in a rock to the west of Flatmark.

Ilmenite, undoubtedly of secondary origin, occurs in a rock to the west of Flatmark.

Apatite may possibly have been introduced into some rocks.

Granodioritic and granitic gneisses.

The table, Nos. 15, 17, 19, 21, 22, gives the mineral contents of some of these rocks, with short descriptions in the text accompanying the table.

The original rocks in the areas here considered have already been stated to be plagioclase gneisses very poor in potash feldspar; wherever potash feldspar occurs in greater amounts it is of secondary, replacement origin. This may seem a perfect example of a vicious circle, but it is especially the microscopical structure of the potash feldspar and its relation

Fig. 13. Granodioritic gneiss E290 46 (No. 15). Microcline (cross-hatched) and plagioclase (light) and a few grains of biotite (b) and epidote (e). The boundaries between plagioclase and microcline (heavy lines) are more irregular than the boundaries between individual grains of either mineral. Note the numerous small inclusions in the microcline. Diameter of picture about 3 mm.

to the plagioclase which give best evidence as to the replacement origin of the former.

For an illustration of the microscopical structures, a rock from the north side of the Finna valley (No. 15) will be taken as an example. What can be seen in other sections studied will only reinforce what can be learnt from this rock. The rock occurs in close association with the plagioclase gneiss, No. 14; the latter is a dark, fine-grained, homogeneous rock, while the microcline-bearing gneiss now to be described has light streaks of more coarse-grained minerals alternating with dark streaks of more fine-grained material. The minerals of the rock are the same as in the associated plagioclase gneiss, with the addition of microcline and myrmekite. Some parts of the rock, rich in biotite and epidote, (corresponding to the dark fine-grained streaks) display a microscopical picture practically identical to that of the plagioclase gneiss. Within a field of vision 2 mm in diameter there may be almost no potash feldspar. Then areas may be found where numerous grains of potash feldspar, many of them very small, wind in between the plagioclase and quartz grains with the most irregular and bizarre outlines imaginable (Fig. 12). In such parts of the rock there is considerably less biotite and epidote. Then there are areas with almost no biotite and epidote, and where the microcline has grown into large porphyroblasts, up to 3 mm in sitze. Inclusions of plagioclase occur chiefly in the larger grains of microcline, the plagioclase

Fig. 14.

Inclusions of plagioclase in a porphyroblast of microcline in granodioritic gneiss E28v 111 (No. 17). The three grains in the centre of the picture are in the same optical orientation. x 18, nic. +.

Fig. 15.

Fig. 15. Inclusion of plagioclase in a porphyroblast of microcline, granodioritic gness E28v 109, Tjernsletten, 3 km south-east of Bjorli. x 35, nic. +.

often being myrmekitic (myrmekite is described and discussed ante p. 21). Sometimes the plagioclase inclusions in microcline have fringy borders, concave outlines also being found, which indicates a partial resorption of the plagioclase. In some cases two or more grains of plagioclase, separated from each other within the section, are in the same optical orientation and are thus indicated as remnants from the resorption of a larger grain.

As illustrations are felt to be more convincing than descriptions, some photographs and drawings of the structures described are presented for study (Figs. 12—15). Anyone claiming the potash feldspar as an original constituent of the rocks here described would certainly be at a loss to explain why that mineral does not occur in a regular crystalloblastic structure such as is generally displayed by the plagioclase of the gneisses. Certainly the plagioclase gneisses may in some cases show irregular structures with sutured margins of the grains, but not to the same great extent or so generally as in the case of the microclinebearing rocks.

Scapolite — amphibole gneisses and other rocks apparently influenced by lime metasomatism.

In the section near Grotli (Fig. 4 on p. 13) the rocks are partly grey plagioclase gneisses (No. 3), but for a great part also rocks rich in scapolite and ampibole. Megascopically some of the scapolite — ampibole rocks can not be distinguished from the common grey geisses, others attract the attention already at a field inspection by a vivid green colour. A rock of this type has the following composition (per cent of volume):

Quartz	32
Plagioclase	8
Microcline	9
Amphibole and pyroxene	30
Scapolite	10
Biotite	11

The amphibole found in this rock has faint absorption colours and a large axial angle, just perceptibly negative. The quartz, together with rather much of microcline, forms veins in the rock, the other minerals are arranged in rows between the quartz veins. The plagioclase is much altered, with numerous inclusions of muscovite. Amphibole, pyroxene and scapolite occur in rather large grains, 2—3 mm in length. Scapolite has been found in symplectitic intergrowth in a porphyroblast of microcline, which indicates the introduction of potash feldspar into the rock as simultaneous with the scapolitisation. Apatite has been found in a porphyroblast of 2 mm length, the relatively large size may point to a secondary formation of the mineral.

Another rock from the same section is of the type megascopically indistinguishable from the common grey gneiss. It is a quite similar scapolite — amphibole rock, but lacks the pyroxene.

In the case of the rocks described above there should be no doubt of the replacement origin of the calcic minerals, scapolite, amphibole and pyroxene. As indicated on the section fig. 4 spots with the same colour as the green scapolite — amphibole rock has been observed in the quartzite. We here apprently have a case of chiefly a lime metasomatism. The scapolite, of a composition about Ma55 Me45 most probably is more calcic than was the plagioclase originally present in the rock, and, also, the formation of amphibole and pyroxene demands an addition of lime to the rock. The occurrence together of amphibole and pyroxene in the green rock may be due to a surplus of lime (in excess of the ratio lime to iron and magnesia in amphibole), as is the case in the diopside amphibolites described by Eskola in the Orijärvi area (Eskola 1915, p. 132).

Scapolite, in small amounts and with an apparent replacment relation to plagioclase, has also been found in an amphibolite from the top of Trollvasstind in Romsdal (specimen and section in the collection of the Geologisk Museum at Oslo).

A number of plagioclase gneisses from Romsdal contain amphibole as large, irregularly branched porphyroblasts with a scattered and uneven distribution within the rock. Generally the amphibole porphyroblasts contain inclusions of biotite with irregular, fringy outlines, indicating a partial resorption of the biotite (Fig. 16). The amphiboles have strong absorption colours and in most cases smaller negative axial angles than found in common amphibole (2V — 30° — 60° app.). In a rock from Ormheim (near Verma) a small grain of scapolite was found associated with an amphibole porphyroblast. This observation is of some interest as a possible link of the formation of amphibole in these rocks with the scapolite — amphibole rocks of Grotli. In the rocks here considered potash feldspar occurs in small amouns only, and the granitisation of the rocks is thus in an incipient stage (Nos. 5, 6). Similar amphibole with very strong absorption colours has also been found in a few cases in granitic rocks rich in potash feldspar, in these cases the amphibole occurs in very small amounts.

In a hand specimen of pegmatite from Stuguflåten (situated in the westernmost part of Lesja), now in the Geologisk Museum at Oslo, it is seen that rather large grains of amphibole are found near the selvage of the pegmatite. This is a formation of amphibole which is probably of a similar nature to that described above.

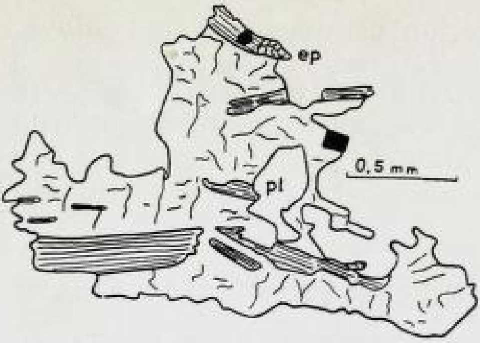


Fig. 16. A porphyroblast of amphibole from plagioclase gneiss D27v 108 (No. 6) whith inclusions of biotite. Also a few grains of iron ore (black), epidote (ep) and an inclusion of plagioclase (pl).

In this connection also a rock from Romsdal will be described. The rock is known to the writer from a hand specimen and section marked RdBI 16 in the Geologisk Museum, the locality is given as west of Flatmark. Megascopically the rock is seen to contain dark inclusions of about centimetre size in a light greenish matrix. In the greeish matrix there are numerous grains of epidote and clinozoisite, between which there is a turbid ground-mass with small, irregular grains of muscovite and chlorite. In the black inclusions a blueish-green amphibole (— 2V 50° app.) is found as highly-branched porphyroblasts. Ilmenite is found in numerous small grains (some of them showing hexaedric outlines) and in larger porphyroblasts of 5 mm size. Apatite occurs in relatively large amonts and also in some larger grains (diameter 0. 5 mm in a section normal to the axis c), and is thus possibly of secondary origin. Both quartz and potash feldspar are absent from the section, the turbid matrix mentioned above may be remnants of plagioclase.

The host of this metasomatic rock is unknown.

Discussion on genesis and geological age of the rocks.

The facts presented, the next step will be to interpret the rocks as to origin and further history. Also in this section the plagioclase gneisses and the granitic gneisses will be dealt with separately.

The plagioclase gneisses and associated rocks.

The geometric analyses in table 1 show the grey gneisses to be quartz — plagioclase — biotite rocks, occasionally also with garnet and amphibole. Even in the absence of chemical analyses the mineral content marks out the rocks as being poor in potassium. There may be about one per cent, or often less, of potash feldspar as inclusions in antiperthite, most of the potassium entering into biotite and certainly also as solid solution into plagioclase.

The plagioclase gneisses may be either metamorposed magmatic rocks or products of metasomatic alteration (granitisation) of sediments.

In the first case they may be of volcanic or plutonic origin and are marked as of a quartz-dioritic composition, thus characteristic members of a rock suite of Pacific type.

In the second case the gneisses must have originated from sediments, probably for the greater part of an argillaceous composition, by addition of mainly sodium and lime. The rocks did not reach that stage in the granitisation process at which an addition of potassium takes place.

From a mere consideration of probabilities we can say that rocks of both the two modes of origin ought to be represented in an area of so wide an extension as the one dealt with here. Certainly the rocks show some features which may be taken to indicate one or the other mode of origin, but much work is needed before the conclusions can be of any greater value.

As already mentioned (p. 11), parts of the gneisses are almost massive rocks without plane foliation. This texture of the rock may indicate a plutonic mode of origin.

On the other hand some especially fine-grained gneisses (No. 1, and also a rock from Stryn, Nordfjord, with grain size 0.05—0.10 mm) may be indicated as of volcanic origin. These rocks contain some much larger grains of plagioclase or quartz, with some good-will this feature may be taken to be a relic porphyric structure.

The anorthosite rocks, occuring in relatively thick bands as an integral part of the gneiss complex, must be considered as of a plutonic origin. Barth & Holmsen (1939, p. 17) described an anorthositic rock from the Antarctic Archipelago, occuring as horizontal bands and schlieren in a eucrite gabbro. These anorthositic bands are much smaller than the corresponding rocks dealt with here, but they may of an analogous type, and are also associated with rocks of a similar petrochemical type (quarts diorites and adamelites are dominating rocks in the Antarctic Archipelago). — In the anorthosite of Lesja there are deposits of titaniferous iron ore (Carstens 1928, pp. 75—77), an ore type of undoubted magmatic origin.

The magmatic origin of the amphibolites can scarcely be in doubt. In most cases they occur as narrow bands, reminding of gabbroid intrusions in folded and metamorphosed sediments. By no means do they thus exclude the possibility of their side-rocks being originally sediments or other supracrustal rocks.

Apart from the quartzites of Grotli, which are to be discussed later on, the rocks show no features that point directly to a sedimentary nature. No untransformed relics of sediments have thus been found among the gneisses.

The banding of the gneisses can be interpreted in more than one way, the interpretation of the banding will imply also an interpretation of the genesis of the rock.

Thus the banding may be a primary feature in a plutonic mass. This interpretation may be probable in the case of the grey plagioclase gneisses exposed south of the anorthositic rock of Lesjaskog. Here the gneiss contains bands of anorthosite and amphibolite. The rock is folded, in some cases with an intricate pattern.

In other cases the banding may recall bedding in a supracrustal rock (figs. 2, 3). In this case the banding may be influenced by metasomatic processes or by metamorphic diffusion within the rock, but still it may be a structure prescribed by the bedding.

The banding of gneisses is certainly a difficult problem, and in the case of the present regions it cannot be discussed with any great profit until the rocks have been more intensively studied.

The folding observed in the gneisses is of a pattern reminding of a folded supracrustal series, but also banded structures produced from homogeneous masses can be folded, perhaps with similar patterns.

In the opinion of the writer there are strong arguments for a Pre-Cambrian (Archean) origin of the gneisses in great parts of the areas here considered, from the boundary to the Caledonian sediments in the east and westwards.

Firstly, the gneisses have a sharp boundary to the overlying sparagmites. At the upper surface of the gneiss, sloping down to the east into the fosse of folding, there is certainly no discordance. The upper parts of the gneisses are mylonites of Caledonian origin and with a perfect conformity to the overlying sparagmites. But the sparagmites and other sediments of the same series must be expected to rest on a Pre-Cambrian basement, as they do on the eastern side of the fosse of folding. In the Caledonian cycle we do not know any series of rocks that should have their place beneath them.

Secondly, there is the strong petrographical resemblance of the gneisses here described with a group of Archean rocks in Valdres (Strand 1943). These Valdres rocks come to the surface in two windows surrounded by Caledonian rocks, in the Slidre map-area, the northern one of which is situated 70 km to the south of the gneisses in the Otta valley, they are also exposed farther south in the Aurdal map-area (see the map fig. 1 in Strand 1943).[1]

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[1] In this paper the writer interpreted the Valdres gneisses as sheared and recrystallised plutonic rocks. A narrow stripe with supracrustal rocks, both sedimentary and volcanic, within the Aurdal area, was regarded as an inclusion within a large batholith. Further study has cast doubt upon this interpretation as there seems to be an even transition between the supracrustals and the coarser gneisses to the north of them, wich have

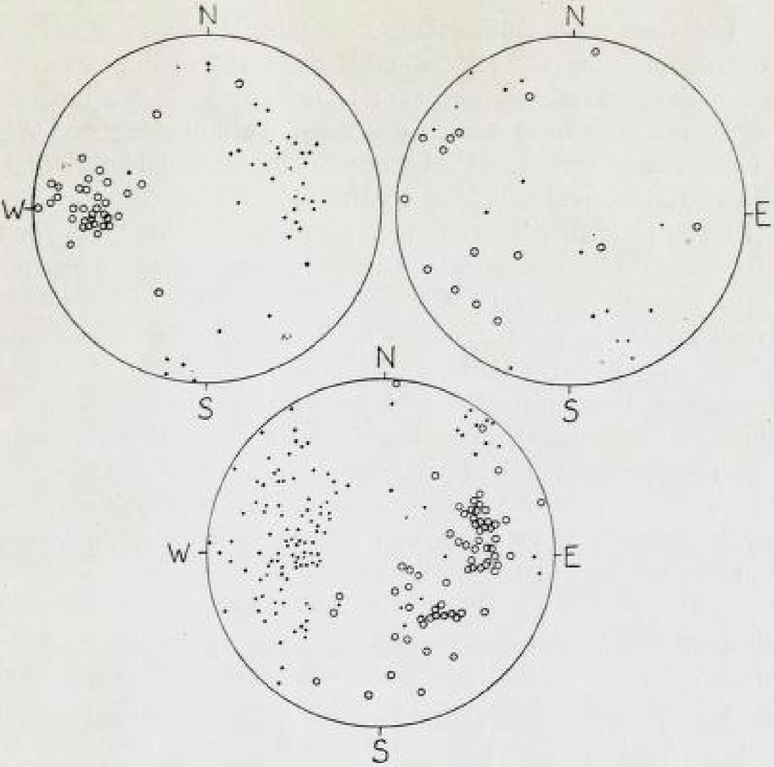

Fig. 17. Tectonical diagrams, equal area projection, upper hemisphere. Rings are the direction of lineation and folding axes, dots are poles of schistosity planes. Upper left diagram: structures measured in the gneisses in the regions Lesja—Bjorli and Otta valley—Grotli. Upper right diagram: same in the Romsdal valley (Verma—Åndalsnes). Lower diagram: same in the Archean plagioclase gneisses in the Aurdal map-area in Valdres, along the Begna valley between Bagn and Leira.

The gneisses in Valdres are of quartzdioritic composition and have the same field appearance as the gneisses here described. Also the anorthositic rocks have their counterpart in

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lost all traces of original structures. Thus great parts of the Valdres gneisses may be of supracrustal origin.

In this connetion attention may be drawn to the coarse augen gneiss in the Aurdal area, which form the boundary between the plagioclase gneisses in the north and granodioritic gneisses in the south. This is certainly nothing but a perfect example of a migmatite front.

the Valdres area. Anorthosites are no banal rocks, and are thus of special value for correlation of the rocks in the two areas.

We may mention here that the anorthosites of the dyke and band type have a wide distribution within the gneiss area. They have been described from Sunnfjord and Nordfjord by N. H. Kolderup (1928), from Nordfjord and Sunnmøre by Eskola (1921), and from regions farther north, west of the Trondheim Region, by Carstens (1928). One of the occurrences of anorthositic rock described by Carstens is found within Caledonian rocks, near the railway station of Drivstua. This rock was also described by Barth (1941).

Returning to the Valdres gneisses, it will be shown that also the tectonics of these rocks lend support to a correlation with the gneisses in the Lesja—Lom—Grotli area, as will appear from a study of the diagrams in fig. 17. We notice an east-west direction of the axes with a pitch to the west in Valdres and to the east in the north-western areas.

This east-west direction in the Archean structure of the gneiss has evidently been impressed upon the boundary of the fosse of folding in the Otta valley in the south and in Lesja in the north.

In the lower parts of the Romsdal vally (upper right diagram in fig. 17) the tectonic axes have a north-east—south-west and north-west—south-east trend, a pattern of a Caledonian type.

Indications of a Pre-Cambrian age of parts of the gneisses in our area are also given by titaniferous iron ore deposits of the Raudsand type (cf. ante, p. 8). The occurrence in Lesja has already been mentioned, another occurrence is at Hanedalstind on the south-western side of the Rauma valley, south-west of Verma (Foslie 1925).

There are at present no equally strong indications of a Caledonian age of greater parts of the gneisses within the areas here dealt with. As mentioned above, the tectonical pattern in the lower part of the Rauma valley seems to be of Caledonian trends. But in the present state of knowledge we should perhaps not attach too much importance to such indications.

The geological conditions in the region of Grotli, which are demonstrated on the sketch-map fig. 18, may call for some

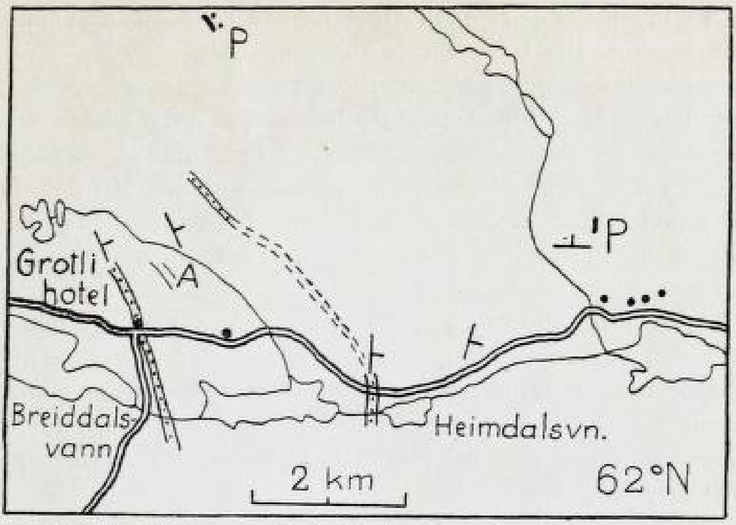

Fig. 18. Sketch map of the Grotli region. Dotted — quartzite, A — anorthosite, P — peridotite

comment in this connection. The quartzites of this region may be Sparagmitian rocks, in that case the gneisses interbedded with them should be transformed sediments of the Caledonian cycle. Regarded by themselves, however, the quartzites might equally well be of Pre-Cambrian age.

Enclosed in the gneisses of the Grotli region there are two occurrences of peridotites. These occur as lense-shaped bodies and are exactly of the same type as the peridotites, often serpentinized, which occur as intrusions in the lower part of the Cambro-Ordovician sequence of the Trondheim Region. There is scarcely any doubt that all the peridotites of this type, also represented by many other occurrences within the gneiss area, are of Caledonian age (Foslie 1925, pp. 26—27).

These peridotites thus give some indication that their gneissic side-rocks should be transformed Caledonian sediments. The quartzites occurring in connection with the peridotites strengthen this argument in the case of the present region. Probably we here have one, or more, synclines of Caledonian rocks in the Pre-Cambrian basement. Then the quartzites get a very natural explanation as Sparagmitian rocks, stratigraphically being the lower part of the transformed Caledonian sediments and marking the boundary of the synclines.

In the greater parts of the area the gneisses are in the amphibolite facies proper, in which calcic plagioclases of all grades can exist. Various grades of the epidote amphibolite facies (with albite or oligoclase together with epidote) are found in regions near the boundary of the fosse of folding in the Otta valley. In this region also the Caledonian rocks are in corresponding mineral facies.

A feature shown by practically all the plagioclase gneisses and also by the anorthositic rocks is the inverse zoning of the plagioclases. This indicates a history of recrystallization common to all the rocks. If parts of the rocks can be proved to be of Caledonian age, then this recrystallization must have taken place n Caledonian time.

The granodioritic and granitic gneisses.

These rocks were formed from the plagioclase gneisses by a granitisation process. A recent definition by Read (1944, p. 47), is as follows: "granitisation means the process by which solid rocks are converted to rocks of granitic character without passing through a magmatic stage."

In the case of sedimentary rocks of argillaceous composition the process of granitisation is an extended one, in which many stages can be distinguished. As has already been referred to, one of these stages may be represented by plagioclase gneisses similar to those of the present regions. During the granitisation by migration of material sodium and lime travel outwards in advance of the potassium, and the first feldspar to be formed in a micaschist under transformation to a granitic rock is albite or a more calcic plagioclase. Thus in some cases gneisses with great amounts of plagioclase may be formed before any notable amounts of potash feldspar is being introduced.

It seems to be a more common case that potash feldspar is introduced before any larger amount of plagioclase is present in the rock. In Goldschmidt's transformation series from the Stavanger area (1921, p. 117) the albite porphyroblast schist contains about 30 per cent of albite and epidote, and the further increase in the amount of feldspar, in the following augen gneisses, takes place by the introduction of potash feldspar.

The geochemical changes leading to granitisation have been demonstrated by Lapadu-Hargues (1945) in a statistical study of a great number of rock analyses, forming a series of the following seven groups: argillaceous shales, phyllites, micaschists, micaceous gneisses, and three further groups of granitic rocks. In the four first groups there is a steady increase in the amount of sodium and lime (in proportion to alumina, used as a substance of reference). In the three following groups, comprising granitic gneisses, there is an increase of potassium and a sharp decrease of iron and magnesia.

It is just this stage in the granitisation process which is shown by the rocks of the present area. It will evidently make no difference whether the chemical composition of the plagioclase gneisses had been achieved by the addition mainly of sodium and lime to a sedimentary rock or it had been retained since their mise-en-place as magmatic rocks. In either case the further history of the rocks would be the same.

Neither will it make any difference in this respect whether the plagioclase gneisses are of Pre-Cambrian or of Caledonian age.

Evidence of the secondary introduction of potash feldspar into the rocks has already been given in the descriptive part of this paper. Attention may again be drawn to the granodioritic gneiss (No. 15, p. 25), in which stripes of a mineral composition practically identical with that of the associated plagioclase gneiss (No. 14) alternate with stripes rich in potash feldspar, displaying a most irregular structure, which impresses the conception of corrosive replacement processes upon an observer. Also the two rocks from Lesja, the specimens taken from the same boulder, (Nos. 16—17) give a conclusive evidence. An example of granitisation by the formation of coarse veins in the rock is given by the hand specimen from Videseter (fig. 8).

Any one questioning the granitisation processes here claimed to have taken place, will have to consider the granitic rocks as original parts of the same complex together with the plagioclase gneisses. Not a single outcrop has been found which shows a granite with intrusive relations to surrounding rocks; the boundaries between the various rock types show concordant banding, or else they are wholly diffuse. There are here no intrusive granites which can be held responsible for the granitisation. Some of the larger pegmatites of the area have the appearance of being intrusive magmatic rocks, but even if they are, they are too small and too few to be capable of producing such effects. Thus, if granitic magma should be invoked as the cause of the granitisation in the present case, it could be in a very indirect way only, by the action of masses far below the present surface.

The granitisation in the present case is one by migration of material (Stoffwanderung, Wegmann 1935, p. 318 f., abstract in Read 1944, p. 68 f.), and displays all the characteristics of this type of metasomatic processes. The structure shown by the innumerable small grains of potash feldspar creeping in between the minerals of the host rock points to a penetration of the rock by material in a highly dispersed state. No movements have taken place in the rocks during or after these processes, otherwise the preservation of the delicate replacement structures would have been inexplicable. To judge from all the evidence, this is a case of replacement with a preservation of the geometry of the rock and with a constant volume. This implies also a removal of material from the rock.

No analyses have been made of the rocks, and even if such were available, a wholly exact determination of the pre-granitisation chemistry of each particular rock would be impossible. Yet the changes in mineral composition, which can be inferred from microscopical studies of the rocks, give a good picture of the main chemical alterations. We may speak of a potash metasomatism, as the amount of potash feldspar increases, for parts at least, at the expense of the plagioclase. Silica must also have been introduced, as the amount of quartz has a tendency to increase. The decrease in ferro-magnesian minerals is also apparent, in many cases even from a field inspection of the rocks. The elements which have wandered away from the rocks are thus iron and magnesia, lime and possibly also sodium.

In the eastern part of Lesja the granitisation produced homogenous granitic rocks in masses large enough to be marked on a map. In the other areas here described this is not the case. In some tracts there may be large masses of rocks very little affected by the granitisation. Then in other areas we have an alternation of almost unaltered plagioclase gneisses and more or less thick bands of granitised rocks. For some unknown reason the invading material seems to have found an especially good opportunity of penetrating and reacting with selected parts of the rocks. Then we have areas where the granitisation action has concentrated on veins of different thicknesses, and thus it was that the veined gneises in the lower part of the Romsdal valley have been produced. Generally the veins are concordant with the foliation, but we find also cross-cutting veins in more than one direction, as observed at Videseter.

The rocks rich in lime described from Grotli and from west of Flatmark may have been formed by transfer of lime, though the Grotli rocks may also have been originally calcareous sediments.

The growth of amphibole porphyroblasts at the expense of biotite in some of the gneisses indicates a transfer of lime. Also the inversely zoned plagioclases found in practically all the rocks may mean an addition of lime in increasing proportions during the crystallisation. But it may also mean that plagioclase with an increasing anorthite content was formed by increasing temperature at the expense of epidote once present in the rock.

There can scarcely be any doubt that the granitisation and other metasomatic processes took place during Caledonian time. In the parts of the gneiss area of Pre-Cambrian origin we can certainly not exclude the possibility of similar processes in Pre-Cambrian times. In the present area there is, however, nothing that points to the presence of more than one generation of potash feldspar (except for the inclusions in the antiperthites).

Indications of a Caledonian age of the granitisation are given by the conditions in Lesja, where the migmatite front ends upwards at a plane parallel to the boundary between the gneiss and the Caledonian sediments. In case the granitisation here were of Pre-Cambrian age, this would be a very strange coincidence. — Quite decisive in this respect is the fact that the migmatite front ascends into Caledonian rocks. At the northern side of the Otta valley the rocks of the dark sparagmite division, which are below the light sparagmites, stratigraphically as well as tectonically, have been transformed into augen-gneisses. The same is the case with the corresponding rocks in Gudbrandsdalen, farther north.

It may be argued that the formation of augen-gneisses from sparagmites is a crystalloblastesis of the feldspar already present in the rock and thus not a case of granitisation. Now the dark sparagmites discussed here were quartz — albite — epidote rocks, and the secondary introduction of potash feldspar into them is proved by replacement structures of the same type as those in the plagioclase gneisses described above.

Study of the microscopic structures shows that no movements have taken place in the rock during or after the introduction of the potash feldspar (ante, p. 38). Exceptions from this rule have been noticed by field observations in a few places, where pegmatite parts of the gneisses can be seen to have been sheared and mylonitised. This is the case at some localities near to the boundary of the fosse of folding. The granitisation is thus not younger than the latest Caledonian movements.

Quantitative data on the rocks.

The table gives the mineral content of a number of the rocks in per cent of volume according to Rosiwal measurements. A × denotes that the mineral occurs in an amount of less than 0.5 per cent. Brief notes of the rocks are given below.

No. 1. E29v 102. Fine-grained grey gneiss, at the river Brettinge at the north side of the Finna valley. The plagioclase is oligoclase — andesine with inverse zoning An 25—35, with grain size 0.2—0.4 mm, with a single grain of 2 mm size in the slide. Biotite is dark greenish brown and amphibole blueish green.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Quartz	11	24	46	43	14	26	25	36	34	6			43	16	16	10	23	15	37	4	41	15
Potash feldspar			1	1	2	1		3			×				22	4	16	1	32	5	25	18
Plagioclase	64	55	30	47	66	56	64	48	44	65	93	98	49	46	41	81	50	66	30	57	32	53
Myrmekite															2		1		×		×	
Epidote	6	6	1		2	1					3	×		9	5	×		1		3		3
Biotite	14	15	22	8	14	13	8	13	20	9	4			27	14	3	5	17	1	21	2	9
Muscovite							3						8			2	5					
Amphibole	5				2	3				20		2								10		
Garnet									1													
Sphene	×	×		1	×	×	×							2	×			×		×		1
Iron ore		×		×	×	×	×	×	1	×						×		×	×			1
Apatite			×	×	×	×	×	×	×	×				×	×			×		×		×

No. 2. HGM I 7, Geol. Mus. Oslo. Albite — epidote gneiss, Lomskollen at the south side of the Otta valley. The albite occurs as larger grains of millimetre size as well as in small grains of about 0.1 mm size. Many of the albite grains show the structure described on p. 18.

No. 3. D28v 107: Dark grey gneiss, Grotli, in the western part of the section fig. 4. Plagioclase, some of the grains zoned, An 24—33, is often antiperthitic with numerous spindle-shaped inclusions of potash feldspar, grain size varying from 0.4 mm, up to 1—3 mm. Most of the quartz occurs on veins of 0.5 to 1 mm width.

No. 4. 37C 104. Light grey gneiss, road section just north of the railway station of Bottheim. Antiperthitic plagioclase, zoned An 25—35, occurs as smaller grains of 0.3—0.6 mm size and as larger grains of 1—2 mm size. Quartz occurs on veins of 1 mm width.

No. 5. GV II 14, Geol. Mus. Oslo. Plagioclase gneiss, Ormheim, near the railway station of Verma, Romsdal. Plagioclase, zoned An 28—38, in grains of 0.2 to 1 mm size. Green amphibole with strong absorption colours occurs in large, branched porphyroblasts. One small grain of scapolite (0.4 mm), associated bith amphibole, has been identified in the slide (cf. p. 28).

No. 6. D27ø 108. Plagioclase gneiss, at the road at the foot of Romsdalshorn, between Flatmark and Åndalsnes. Plagioclase, zoned An 25—35, in part antiperthitic, in grains of 0.5 to 1 mm size. Amphibole in large, branched porphyroblasts (fig. 16), with strong absorption colours, —2V 60° app.

No. 7. D27ø 105. Light, fine-grained plagioclase gneiss, loose boulder Flatmark, Romsdal. Plagioclase, zoned An 23—27, in grains of about 0.5 mm size. Muscovite occurs in large, fringy porphyroblasts.

No. 8. RdB I 13, Geol. Mus. Oslo. Coarse-grained plagioclase gneiss, Åndalsnes. Plagioclase zoned An 25—30, in grains of 2—3 mm size.

No. 9. D27v 107. Coarse-grained plagioclase gneiss, road section west of Veblungsnes, about 2 km south-west of Åndalsnes. Plagioclase some of the grains zoned, An 35—45, of 2—3 mm size.

No. 10. D28ø 103. Dioritic gneiss or amphibolite, Veslefjell east of Grotli. Granoblastic structure with plagioclase grains, often zoned An 30—40, up to 1 mm size.

No. 11. E28v 108. Anorthositic schist, Lesjaskog (p. 12). Most of the plagioclase grains with distinct inverse zoning, An 40—60, of millimetre size.

No. 12. D28v 101. Anorthositic schist, Grotli (p. 12). Plagioclase grains with distinct inverse zoning, An 40—60, of millimetre size.

No. 13. E29ø 224. "Leuko-gneiss", at the brook Kvitgrove at the north side of the Finna valley. The plagioclase is albite—oligoclase, An 10. Granoblastic structure with grain size about 0.5 mm. — Light rocks of this type occur as bands in the gneisses at the north side of the Finna valley.

No. 14. E29ø 47. Dark fine-grained gneiss, at the brook Lauva at the north side of the Finna valley. The plagioclase is oligoclase, An 20, some of the grains show a faint zoning. Regular crystalloblastic structure with grains of quartz and plagioclase of 0,2—0.4, up to 0.8 mm size, biotite in subparallell grains up to 1 mm long.

No. 15. E29ø 46. Granodioritic gneiss, locality as preceding. Description in the text p. 25.

No. 16. E28ø 102. Fine-grained light grey gneiss, loose boulder, mountain plateau north of Lesja (p. 14). Regular granoblastic structure, plagioclase, zoned An 15—22, in grains of 0.1—0.5, up to 1 mm size. Potash feldspar in small grains between the corners of the plagioclase grains. — The low content of quartz within the slide may be accidental, there is a quartz vein at the edge of the slide.

No. 17. E28ø 103. Granodioritic gneiss, from the same boulder as the preceding. The plagioclase is oligoclase, zoned An 10—20, in grains of the same size as in the preceding rock. Potash feldspar in small irregular grains and in large porphyroblasts up to 5 mm size, with numerous inclusions of plagioclase. Quartz occurs on veins in the rock. Both muscovite and biotite occur in much larger grains than in the preceding rock.

No. 18. E28v 110. Speckled rather massive gneiss, alternating with bands of light reddish gneiss (No. 19), road section 1 km west of the church of Lesjaskog. Plagioclase antiperthite, zoned An 20—25, in grains with irregular outline of 1—3 mm size. Quartz occurs in small irregular grains within and between the plagioclase grains.

No. 19. E28v 111. Light reddish granodioritic gneiss, associated with the preceding rock. Microcline occurs as porphyroblasts of 2—4 mm size and in smaller grains with irregular outline penetrating in between the plagioclase grains. The latter are more saussuritized than in the preceding rock, most of them have fringy outline with an appearance as partly resorbed remnants.

Nos. 20—21. D29v 101. Dark dioritic gneiss with veins and schlieren of light granitic material, Videseter hotel, Stryn. The dark gneiss (No. 20) has a regular granoblastic structure with plagioclase grains, zoned An 27—31, of 0.2—0.4 mm size. The vein in the slide (No. 21) is 3 mm wide. It contains plagioclase grains of the same size as in the dark rock. The potash feldspar occurs as small irregular grains as well as in porphyroblasts of 2—3 mm size.

No. 22. E28ø 106. Augen-gneiss, at the road on the north slope of the valley between the railway stations of Lesja and Bottheim (p. 14). The rock contains scattered augen of about 5 mm size, consisting of numerous grains of potash feldspar in a matrix of dark plagioclase gneiss, the plagioclase is a sodic oligoclose, An 12—15, in grains of 0.2—0.4 mm size.

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